separation distances greater than about 150 km. If coordination distances were based on short-term propagation losses coinciding with the instantaneous worst-case pointing of the gateway antennas, they would be typically 250 km.

2.6.5 FSS networks using geostationary satellites have successfully shared frequency bands with FS networks for many years. The results of the present analysis indicate that sharing between gateway earth stations in non-GSO MSS networks and the Fixed Service would involve coordination distances of similar order to those in FS/GSO FSS sharing.

Owing to resourcing problems the number of carrier types included in the study has been limited. Nevertheless it is considered that the results justify a provisional conclusion that frequency-sharing between the two services is feasible. Further study, using a greater variety of carrier types is desirable to provide confirmation of this conclusion The impact on sharing with the FS if the MSS Feeder links were to be implemented in reverse-band mode has yet to be considered.

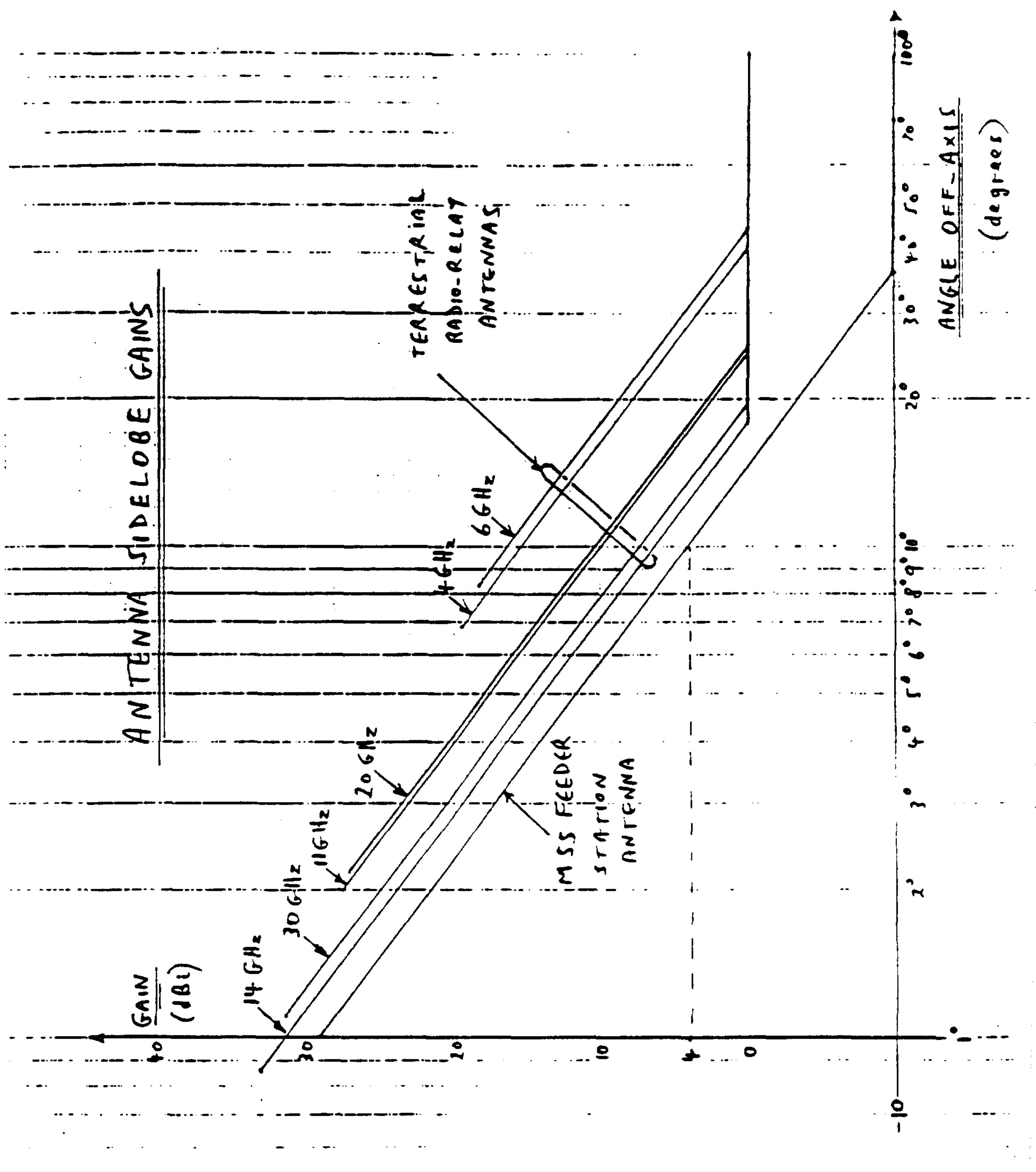


FIGURE 2

ANTENNA SIDELOBE GAINS

FIGURE 6.

Interference Between "Iridium" Feeder Link Earth Station and FS Receiver over a 500 day (43200000 second) period

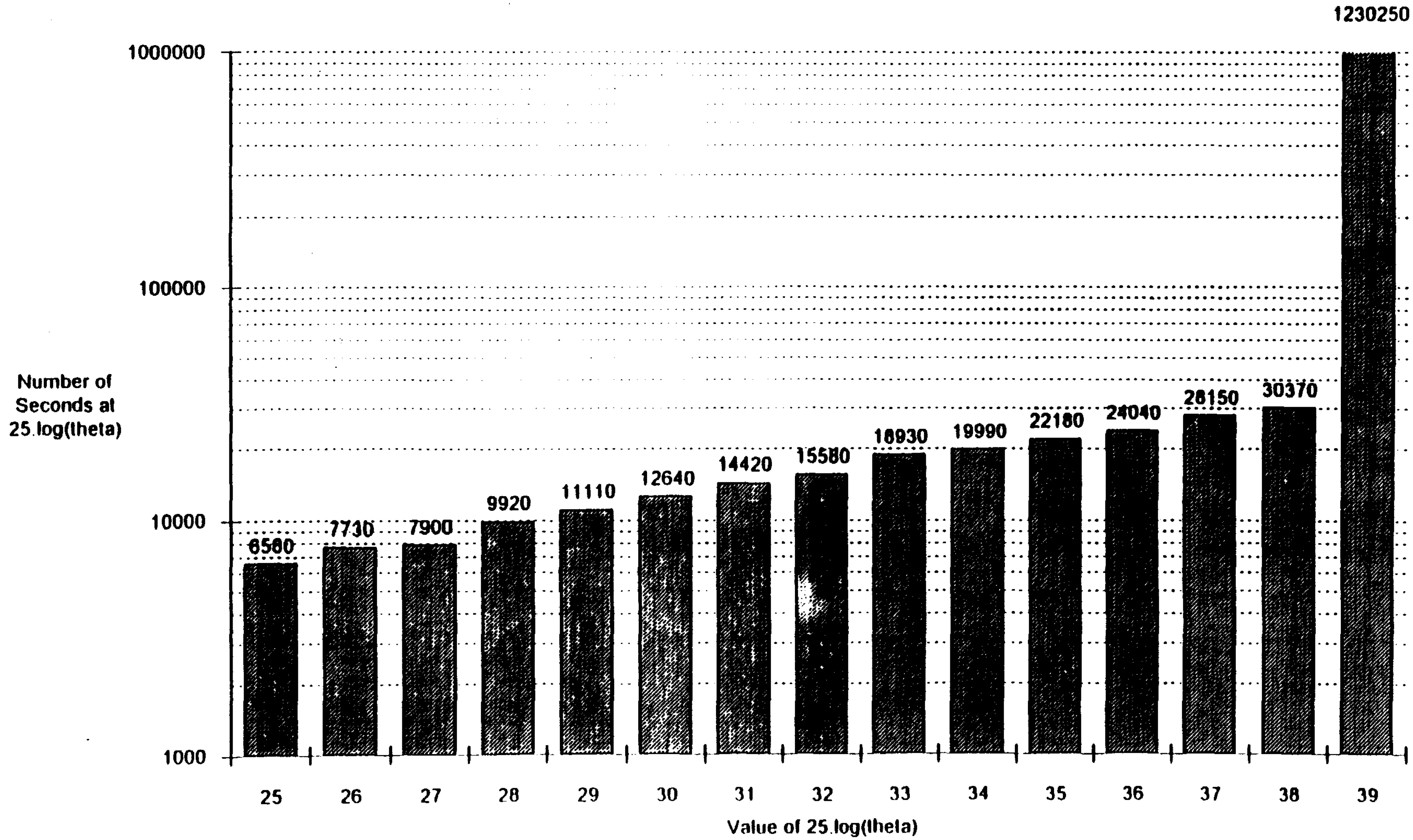


FIGURE 7

Interference Between "Globalstar" Feeder Link Earth Station and FS Receiver over an approx. 400 day (34645930 second) period

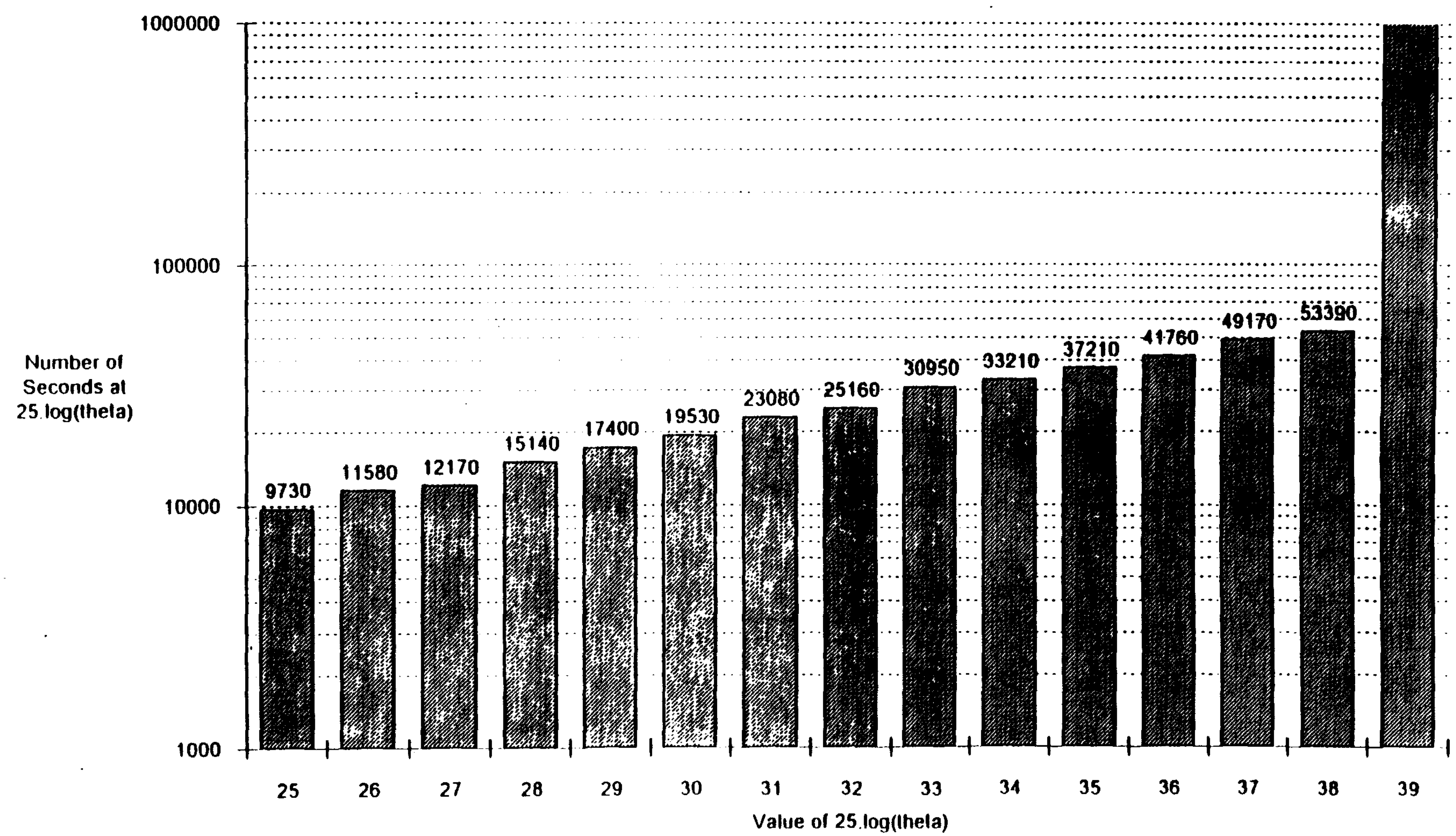


FIGURE 8

Interference Between "Project-21-MEO" Feeder Link Earth Station and FS Receiver over a 400 day (34560000 second) period

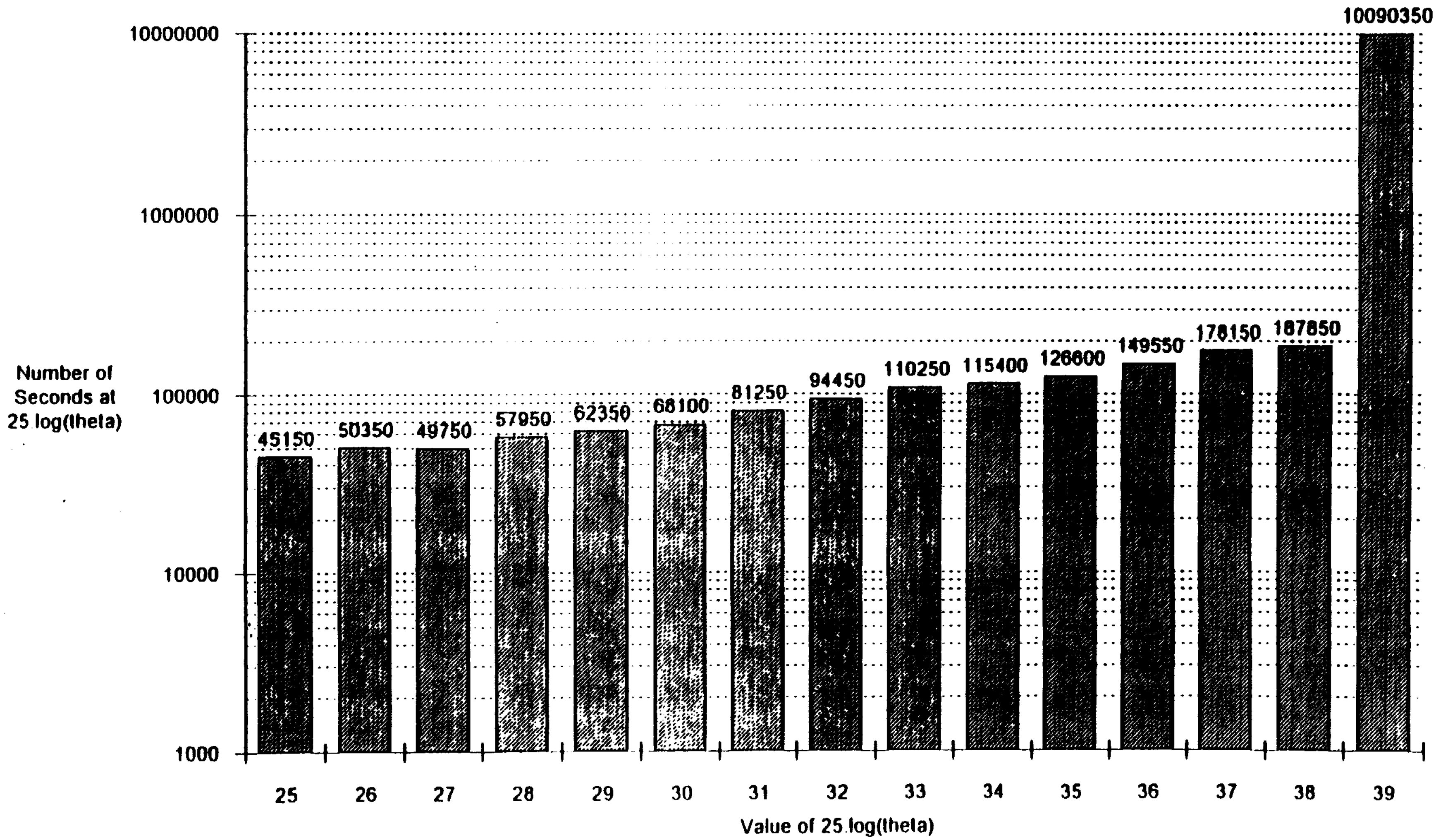
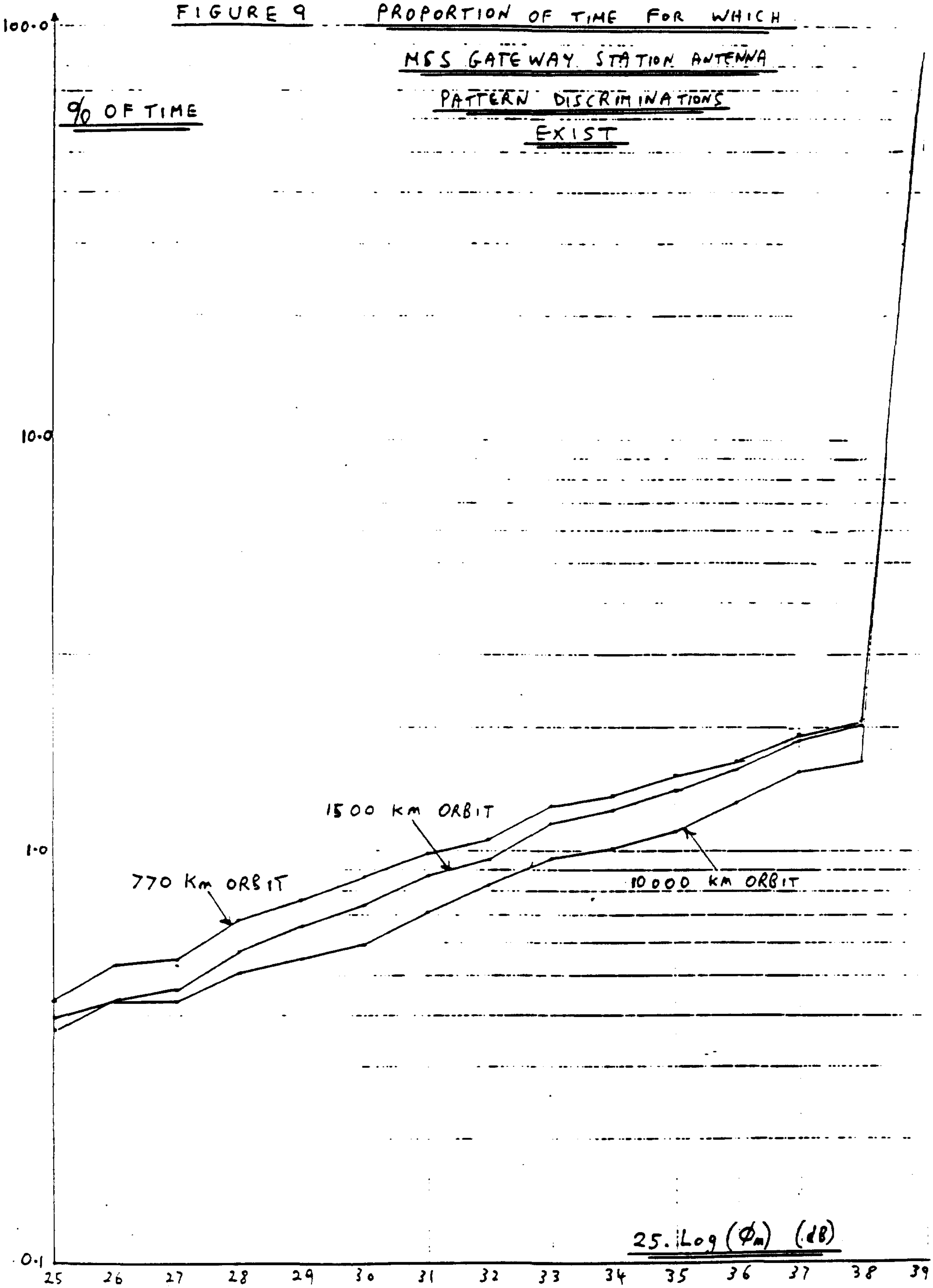


FIGURE 9 PROPORTION OF TIME FOR WHICH MSS GATEWAY STATION ANTENNA PATTERN DISCRIMINATIONS EXIST



CEPT PROJECT TEAM SE 18

CONCLUSIONS TO THE STUDY

"FREQUENCY SHARING IMPLICATIONS OF FEEDER-LINKS FOR NON-GSO/MSS NETWORKS IN FSS BANDS"

3. Conclusions

3.1 Since the question of frequency allocations for non-GSO/MSS Feeder-links has been included in the agenda for ITU WRC-95, ITU-R Study Group 4 will establish Task Group 4/5 to make an intensive study of the frequency-sharing implications during 1994. It is recommended that Administrations of the CEPT should participate in the work of this Task Group. The conclusions drawn here should be regarded as provisional pending the outcome of that work.

3.2 Unless steps are taken to prevent it (eg implementation of RR 2613), whenever a non-geostationary satellite is temporarily in line, or nearly in line, with a geostationary satellite and an earth station, and the two satellites are operating co-frequency carriers, the level of interference into each carrier will greatly exceed the normal level (ie the level sustained for the majority of the time). Assuming that the non-GSO/MSS Feeder-link earth stations will not usually be co-located with the GSO/FSS earth stations, the up-path and down-path 'in-line' events will generally occur at different times, and this will be true for both systems.

3.3 Owing to the severe but short-term nature of 'in-line' interference events, there is a need for the ITU-R to establish criteria for both the maximum permissible level of 'in-line' interference and for the level which may be regarded as an outage; maximum percentages of time for which they can be tolerated should be associated with these two levels. The Project Team's suggestions for digital carriers in GSO/FSS networks are:-

Permissible limit - 12% of the clear-air long-term noise budget should not be exceeded for more than 0.1% (0.05%) of any year, and no individual excess should last for more than 30 seconds.

Outage threshold - 120% (64%) of the clear-air long-term noise budget should not be exceeded for more than 0.01% of any year, and no individual excess should last for more than 10 seconds.

(The percentages in brackets relate to circuits designed to meet ITU-TS Recommendation G.826 while the un-bracketed percentages relate to circuits designed to meet ITU-R Rec.614, which is compatible with ITU-TS Rec.G.821.)

Except in cases where bit regeneration is performed within the satellite payload, these limits should be applied to GSO/FSS carriers from end-to-end (ie including both up-path and down-path interference contributions).

It has not been practicable for the Project Team to develop 'in-line' interference criteria for the non-GSO/MSS Feeder-links, but bearing in mind that Feeder-links are effectively trunk links it is conceivable that similar limits to those above (non-bracketed) would emerge from an appropriate study.

3.4 Based on interference limits similar to those in §3.3 'in-line' event statistics for representative selections of 'wanted' and 'interfering' carriers in C-band/LEO, Ku-band/MEO and Ka-band/LEO networks were computed assuming (in most cases) no satellite beam discrimination and no other means of implementing RR 2613. The statistics included, for both GSO and non-GSO networks, mean and maximum durations of individual events, number of events per day and aggregate event time percentage over many days. Worst instant C/I values were also calculated for each combination of carriers. Review of the results produced the following observations:-

3.4.1 In most cases the shortfall in C/I relative to the assumed protection ratio at the truly 'in-line' instants would be far too great to be ignored, and in a number of cases the assumed outage criteria would be transgressed.

3.4.2 The permissible level of 'in-line' interference assumed would be exceeded for more than the prescribed percentage of time for the majority of GSO/FSS carriers and for the great majority of non-GSO/MSS Feeder-link carriers. The fact that the aggregate time results are considerably worse for the non-GSO/MSS Feeder-link carriers than for the GSO/FSS carriers is due mainly (but not entirely) to the large number of interfering GSO/FSS satellites and earth stations assumed; for much of C-band and Ku-band this assumption reflects reality today, and it is anticipated that it will become true for Ka-band in the foreseeable future.

3.4.3 In general the greater the latitude of the earth station, and the greater its longitude relative to the longitude of the geostationary satellite, the greater will be the percentage of time for which the permissible interference level will be exceeded.

3.4.4 The event durations will be significantly extended in cases where an MSS gateway earth station is located near to an FSS earth station (eg <100 km).

3.4.5 Owing mainly to the fact that the angular velocities of MEO satellites will be only about $^1/_3$ of those of LEO satellites, the mean event durations will be greater when MEO systems are involved than when LEO systems are involved. The mean event duration criteria are likely to be exceeded for both FSS and MSS carriers in the great majority of MEO cases.

3.4.6 Taking observations 3.4.1 to 3.4.5 into account it is concluded that, unless the non-GSO/MSS satellites and earth stations are equipped to implement RR 2613 to protect GSO/FSS networks and the non-regulatory equivalent of RR 2613 to protect their own networks, or an alternative means of avoiding 'in-line' interference is sanctioned by WRC-95, it is probable that frequency-sharing by non-GSO/MSS Feeder-links and GSO/FSS networks will lead to unsatisfactory quality for both services.

3.5 If the non-GSO MSS Feeder-links share frequencies with GSO/FSS networks on the basis of RR 2613 and no coordination procedure is invoked, then stringent EIRP limits on the up-path and stringent pfd limits on the down-path will need to be set for the non-GSO/MSS Feeder-links, in order to protect existing and future GSO/FSS networks. The establishment of a coordination procedure would require action by WRC-95.

The Team considers that, if a coordination regime is established, then a means of determining whether or not an existing or pending GSO/FSS network would be affected - eg a modified form of the RR Appendix 29 method - would have to be adopted. A large number of coordination exercises would probably be necessary for each incoming non-GSO network, and if these were successfully concluded and the network brought into service it may nevertheless be impracticable to protect future GSO/FSS networks adequately.

3.6 Whilst RR 2613 would be relatively easy to implement on the Feeder-link up-paths the Team believes that in most cases its implementation on the down-paths would be very difficult Also, from a preliminary study the implications on service continuity of the non-GSO/MSS carriers would appear to be generally problematical. (If sub-bands which are, and will continue to be, only lightly used by GSO/FSS networks could be employed, it might be possible to limit the impact on the MSS service by implementing RR 2613 to protect only the few GSO/FSS networks which continue to use those sub-bands.)

Furthermore, although RR 2613 affords no protection to the non-GSO/MSS Feeder-links, reliance on its implementation would necessitate the incorporation of features within the non-GSO satellite systems to prevent 'in-line' interference from the GSO/FSS carriers adversely affecting the mobile satellite service.

3.7 Possible alternatives to reliance on RR 2613, each of which would require action by WRC-95, are:-

i) allocation to the non-GSO/MSS Feeder-links of spectrum outside the FSS bands;

ii) exclusion of FSS carriers other than non-GSO/MSS Feeder-link carriers from designated sub-bands within the FSS allocations;

iii) allocation of designated sub-bands within the FSS allocations to the non-GSO/MSS Feeder-links in reverse-band mode; the Feeder-link carriers would be permitted to operate only in reverse-band mode and other FSS carriers would, as at present, be restricted to normal mode.

The Project Team's terms of reference exclude study of alternative (i). A study of alternative (ii) is also outside the Team's competence, except to state the obvious that it would create major difficulties for operators of the 'displaced' GSO/FSS networks.

Alternative (iii) has been investigated in some depth by the Team, using both 'normal' GSO/FSS carrier parameters and also using generalised parameters conforming to RR Appendix 30B. The outcome is that if the Feeder-links were operated in reverse-band mode, the requirements of RR 2613 could be met by restricting the operation of the Feeder earth station antennas to elevation angles above about 10° and no special features would need to be incorporated in the satellites. The studies showed that satellite-to-satellite interference is unlikely to be a problem, and that, whilst earth station-to-earth station coordination along the lines of RR Appendix 28 would be required, coordination distances would be modest provided the Feeder stations were located at reasonable angles to the azimuth pointing directions of nearby FSS/GSO earth stations. To limit the number of such coordinations it would be advisable to avoid frequencies and/or geographical areas heavily used for VSAT and other small-dish networks. It should be noted that in central European countries, for example, the 0.01% of worst month rain attenuation at 30GHz is about 15dB greater than at 18GHz; for this reason above 18GHz the reverse band alternative might create design difficulties for the non-GSO satellite payloads.

3.8 The following conclusions were drawn from the Project Team's study of interference between non-GSO/MSS Feeder links and the Fixed Service.

3.8.1 Almost all the FSS spectrum allocations are shared with the FS on a co-Primary basis; the only FSS allocations not shared with the FS are either not available on a world-wide basis or are likely to be used for small dish FSS applications.

3.8.2 On the down-path non-GSO/MSS Feeder-link carriers are unlikely to exceed the pfd limits prescribed by the ITU-R for the protection of terrestrial radio-relay terminals.

3.8.3 Interference to the up-path Feeder-links of non-GSO/MSS satellites from co-frequency emissions by terrestrial radio-relay terminals are unlikely to exceed, for significant proportions of the time, single-entry criteria based on ITU-R Recommendations for digital FSS carriers.

3.8.4 Provided that the Feeder earth stations to non-GSO/MSS satellites were sited with reasonable angular separations from the principal axes of nearby radio-relay terminals, then for all but about 0.01% of time the interference would be within acceptable limits for separation distances below about 150 km in the case of the Feeder stations and about 100 km in the case of the terrestrial terminals. These figures were derived for over-land propagation paths, but without assuming any site shielding or carrier frequency planning.

Since radio-relay systems use both up and down FSS bands for transmitting and receiving, the Team has no reason to anticipate different general conclusions from a similar study assuming reverse-band operation of the Feeder-links, but it has not carried out that study.

3.9 Overall Conclusion

On the basis of §3.8 the Project Team concludes that frequency-sharing of non-GSO/MSS Feeder links with FS links is feasible in C-band, Ku-band and Ka-band, at least in forward transmission mode.

From §3.4 to §3.6 it is evident that some way of inhibiting or avoiding 'in-line' interference from non-GSO/MSS Feeder-links to GSO/FSS networks, and vice versa, is inescapable for both FSS and MSS networks.

Bearing in mind

a) the difficulties of implementing RR 2613 in the non-GSO satellites,

b) the probably adverse impact of RR 2613 implementation on the MSS continuity of service,

c) the need for a similar means in the non-GSO satellites of overcoming the even greater difficulties posed by 'in-line' interference to the MSS Feeder-links, and

d) the need for either very stringent EIRP and pfd limits to protect GSO/FSS networks, or a complex coordination regime with a large number of coordination exercises per non-GSO network,

in the judgement of the Team RR 2613 does not provide a satisfactory sharing mechanism.

The Project Team was not mandated to investigate the options requiring exclusive frequency allocations or the use of non-FSS bands. Within these constraints it is considered that reverse band working for the non-GSO/MSS Feeder-links, preferably in frequency bands below 18GHz and preferably in sub-bands and/or geographical areas not heavily used by VSATs or other small-dish applications, is a more promising option than implementation of RR 2613.

7

ATTACHMENT 7

Radiocommunication Study Group
Fact Sheet

Study Group: TG 4/5 Date: April 27, 1994

Document: USTG 4/5-8 Ref:

Document Title: Reverse Band Operation of NGSO MSS Feeder Links in the 4.5-4.8 and 6.725-7.025 GHz Allotment Bands

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Purpose/Objective:

To provide information regarding the feasibility of reverse band operation of NGSO MSS feeder links in the 4.5-4.8 and 6.725-7.025 GHz FSS allotment bands.

Abstract:

Studies conducted by Working Party 4A have shown that "in-line" coupling between GSO FSS systems and NGSO MSS feeder link systems operating in forward band mode in FSS bands is likely to occur. This report explores the possibility of operating NGSO MSS feeder links in reverse band mode in the 4.5-4.8 and 6.725-7.025 GHz allotment bands. Using reverse band working, earth station-to-earth station and satellite-to-satellite coupling between MSS and FSS systems must be considered. This report displays the calculated C/I levels at the NGSO satellite when the NGSO satellite is operating its up-link in the 4.5-4.8 GHz FSS down-link band. It also calculates the C/I levels at each allotment band satellite when the NGSO satellite is operating its down-link in the 6.725-7.025 GHz FSS up-link band. The results in this report may be used as a guide for determining whether reverse band working is feasible for particular NGSO systems in FSS allocations.

Fact Sheet Preparer: Julie A. Garcia

Documents
Radiocommunication
Study Groups

Document USTG 4/5-8
27 April 1994
Original: English

UNITED STATES OF AMERICA

Draft New Report

Reverse Band Working of Non-Geostationary Orbit(NGSO) MSS Feeder Links in the 4.5-4.8 and 6.725-7.025 GHz Allotment Bands

1. Introduction

At the WARC '92, spectrum was identified for allocation to the Mobile Satellite Service (MSS) in the 1700 - 2520 MHz frequency range. Feeder links to MSS networks were not included in the allocation. Instead, feeder links were considered to be a matter for coordination and would be provided in FSS allocations. However, studies conducted by Working Party 4A have shown that "in-line" coupling is likely to occur between GSO FSS systems and NGSO MSS feeder link systems when both are operating in forward band mode. The need was identified to develop technical means to facilitate frequency sharing between NGSO feeder links to MSS networks and FSS systems in FSS allocations.

This report analyzes the sharing between NGSO MSS and GSO FSS systems when the NGSO MSS feeder links operate in "reverse band" in the 4.5-4.8 and 6.725-7.025 GHz allotment bands. In this study, NGSO MSS feeder links use the 4.5-4.8 GHz FSS down-link band for their up-link transmissions and the 6.725-7.025 GHz FSS up-link band for their down-link transmissions. These bands are shared on a co-primary basis with the fixed and mobile services. This report does not examine the feasibility of sharing with those services. Further, in the U.S. the use of these bands by the FSS is currently limited to International inter-Continental systems subject to electromagnetic compatibility analysis.

2. Interference Modes

Using "reverse band" working (RBW) the following interference modes occur:

a) GSO FSS satellite interference into NGSO MSS satellites;
b) NGSO MSS satellite interference into GSO FSS satellites;
c) GSO FSS earth station interference into NGSO MSS earth stations;
d) NGSO MSS earth station interference into GSO FSS earth stations.

This report will focus on interference of types a) and b).

3. Interference from the GSO FSS satellite down-link into NGSO MSS satellite up-link

The static or "snapshot" case of interference from a GSO FSS satellite down-link transmitter into the NGSO MSS satellite receiver was analyzed using the worst case geographical and geometrical alignments. The maximum interference occurs when there is a line of sight between the GSO and NGSO satellites in a grazing condition over the Earth's horizon [See Figure 1.]. The worst case trans-horizon satellite-to-satellite carrier-to-interference(C/I) ratios were computed at the NGSO satellite.

The interfering power from the GSO satellite was calculated from the allotment plan parameters (Article 10 of Appendix 30B of the Radio Regulations) using the minimum isolation from the satellite antenna main beam towards the Earth's horizon, yielding a maximum possible value for interfering power. The wanted carrier power at the NGSO satellite was calculated using the parameters in Table 1 for planned NGSO MSS systems. Extreme values of the NGSO satellite receive antenna gain were assumed. The NGSO satellites were assumed to provide coverage down to an elevation angle of 10 degrees.

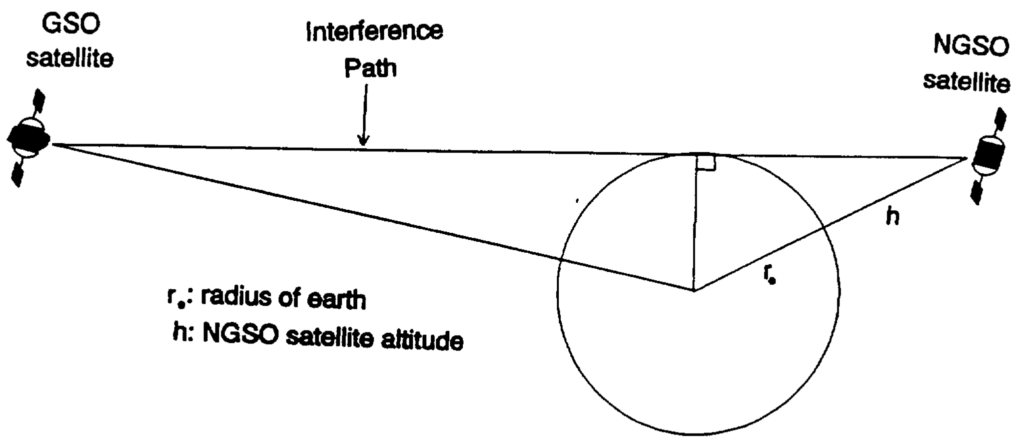


FIGURE 1.

	ORBIT HEIGHT (kM)	GATEWAY E.S. E.I.R.P. (dBW)	SATELLITE E.I.R.P. (dBW/ch)	SPREADING BANDWIDTH (MHz)	RX ANTENNA GAIN, NADIR (dBi)	RX ANT GAIN, EOC (dBi)
GLOBALSTA	1421	28.2	-15.5	1.25	3.0	0.0
ARIES	1020	50.1	-21.3	16.5, .0075	3.4	1.2
ELLIPSAT I	1250	16.2	14.0	1.4	8.0	6.0
ELLIPSAT II (wide beam)	2903	11.0	22.0	1.4	10.0	0.0
ELLIPSAT II (spot beam)	2903	11.0	22.0	1.4	24.0	24.0

TABLE 1 NGSO/MSS Feeder Link Carrier Parameters

3.1 Results

For each of the beams in the allotment plan, the C/I level at the NGSO satellite was plotted with respect to the boresight longitude. The results were displayed in Figures 2. - 6. to show the range in C/I values for each of five different NGSO MSS systems. These results may be used as a guide in determining whether RBW is feasible for particular NGSO systems in the 4.5-4.8 GHz band. The C/I values for each of the systems are positive, indicating the ability of the MSS systems to share the band with existing FSS systems. The low C/I levels in Figure 6. result from assuming the spot beam is pointed towards the

Earth's horizon in this worst case analysis. Low C/I levels at the NGSO satellite can be avoided by ensuring that the spot beam is not directed towards the Earth's horizon.

4. Interference from the NGSO satellite down-link into the GSO FSS satellite up-link

The identical geometry was used to calculate the worst case trans-horizon satellite-to-satellite C/I ratios at the GSO satellite.

The interfering power from the NGSO satellite was calculated using the satellite EIRP from Table 1 and the maximum gain formula and allotment band satellite(ABS) reference antenna pattern from Annex 1 of Appendix 30B. The wanted carrier power at each ABS was calculated from the allotment plan parameters using the ABS receive antenna gain at the half-power beamwidth.

4.1 Results

For each of the beams in the allotment plan, the C/I level at the GSO FSS allotment band satellite was plotted with respect to the boresight longitude. The results were displayed in Figures 7. - 10. to show the range in C/I levels at the allotment band satellites. Appendix 30B states that an aggregate C/I ratio under free-space conditions of 26 dB or higher must be maintained at each ABS. Since the C/I levels in Figures 7. - 10. are much higher than the 26 dB threshold, MSS feeder links operating in the 6.725-7.025 GHz band will not interfere with the allotments.

5. Conclusion

This report examined the feasibility of frequency sharing between RBW of NGSO MSS feeder links and forward-band operation of GSO FSS networks. The C/I levels at each FSS ABS and at several planned NGSO MSS satellites were calculated. The positive C/I values for the NGSO MSS satellites in Figures 2. - 6. indicate that sharing between the GSO FSS satellites and the NGSO MSS feeder link satellites is possible in the 4.5-4.8 GHz allotment band, due to the limited use of this band by FSS systems. The C/I levels greater than 26 dB in Figures 7. - 10. indicate that operation of the ABS in the 6.725-7.025 GHz band will not be affected by MSS feeder link operation. The results of the analyses demonstrate that RBW is a viable means for providing MSS feeder links in frequency bands shared with the FSS, without the need for coordination. However, further study is required to determine the feasibility of sharing with existing high power fixed users and widely scattered mobile users.

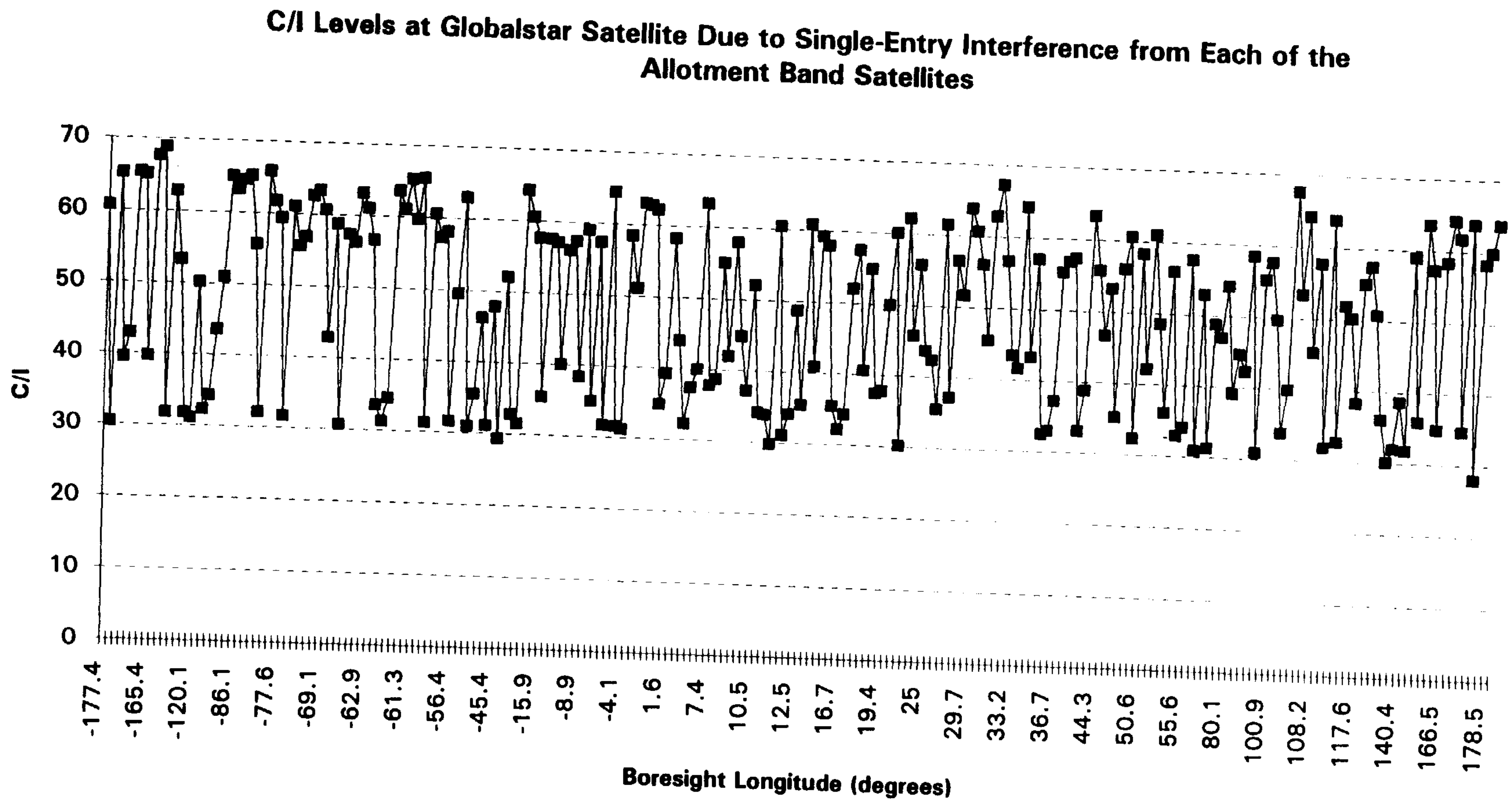

C/I Levels at Globalstar Satellite Due to Single-Entry Interference from Each of the Allotment Band Satellites
C/I
70
60
50
40
30
20
10
0
-177.4
-165.4
-120.1
-86.1
-77.6
-69.1
-62.9
-61.3
-56.4
-45.4
-15.9
-8.9
-4.1
1.6
7.4
10.5
12.5
16.7
19.4
25
29.7
33.2
36.7
44.3
50.6
55.6
80.1
100.9
108.2
117.6
140.4
166.5
178.5
Boresight Longitude (degrees)

Figure 2.

C/I Levels at Aries Satellite Due to Single-Entry Interference from Each of the Allotment Band Satellites

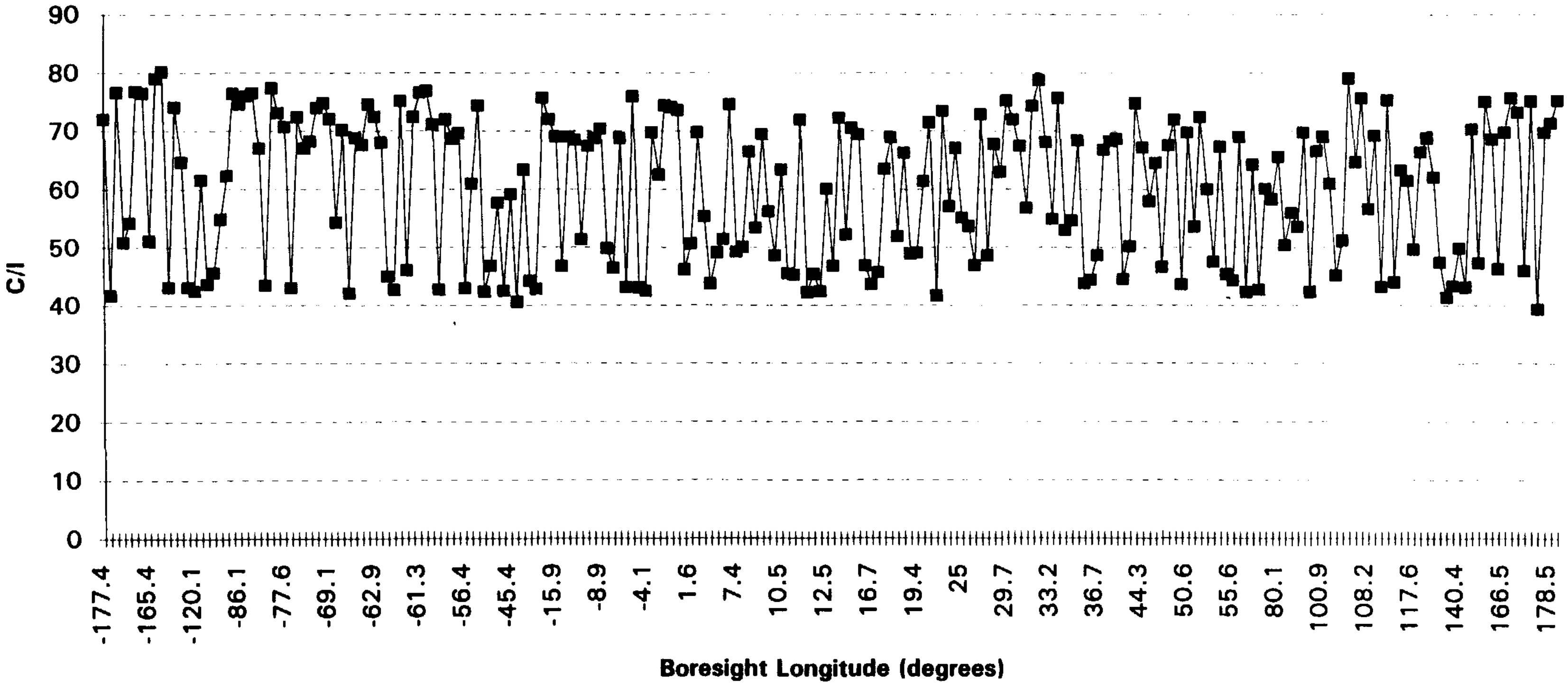


Figure 3.

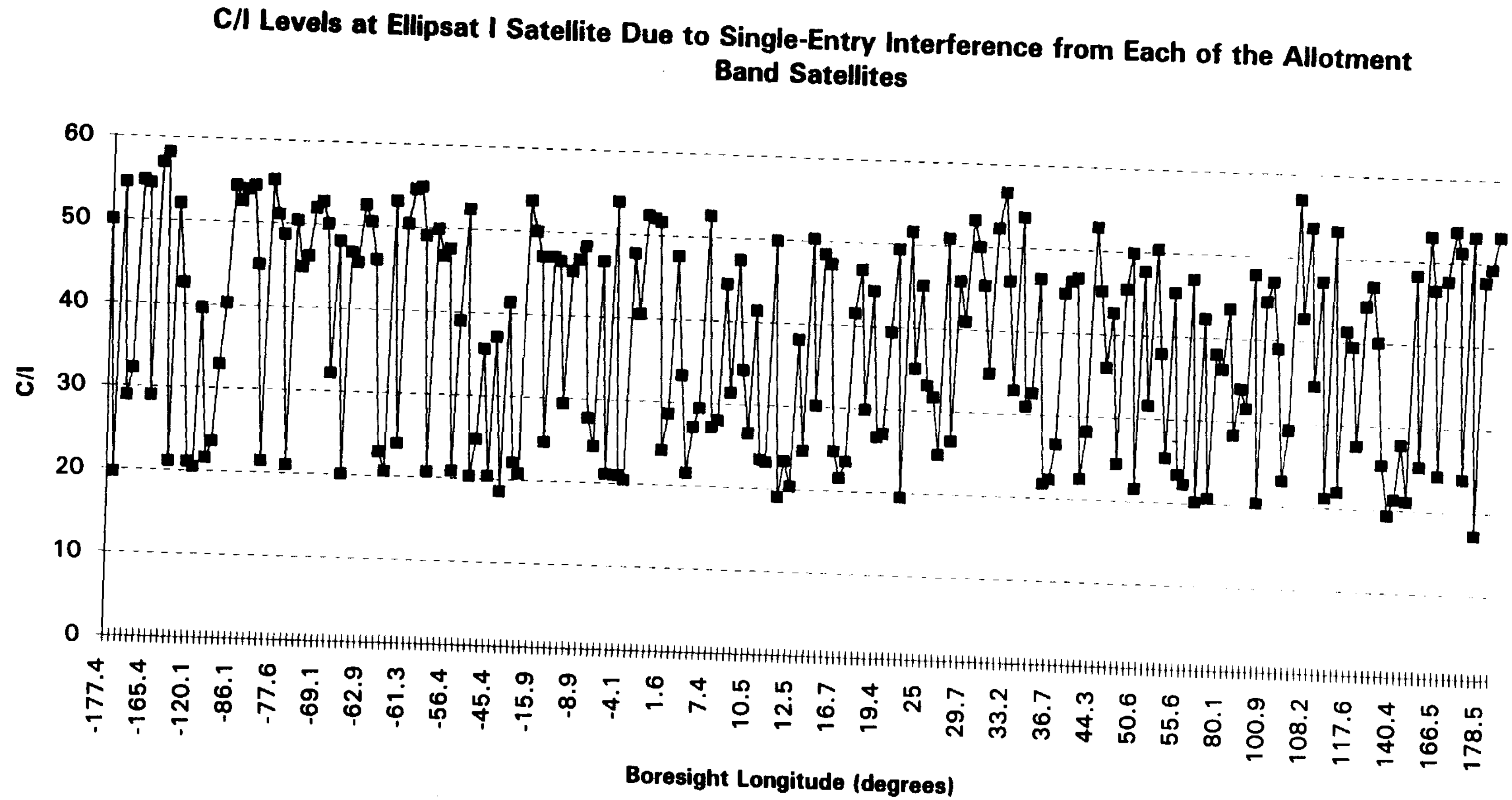

C/I Levels at Ellipsat I Satellite Due to Single-Entry Interference from Each of the Allotment Band Satellites
60
50
40
30
20
10
0
C/I
-177.4
-165.4
-120.1
-86.1
-77.6
-69.1
-62.9
-61.3
-56.4
-45.4
-15.9
-8.9
-4.1
1.6
7.4
10.5
12.5
16.7
19.4
25
29.7
33.2
36.7
44.3
50.6
55.6
80.1
100.9
108.2
117.6
140.4
166.5
178.5
Boresight Longitude (degrees)

Figure 4.

C/I Levels at Ellipsat II Satellite (using wide beam) Due to Single-Entry Interference from Each of the Allotment Band Satellites

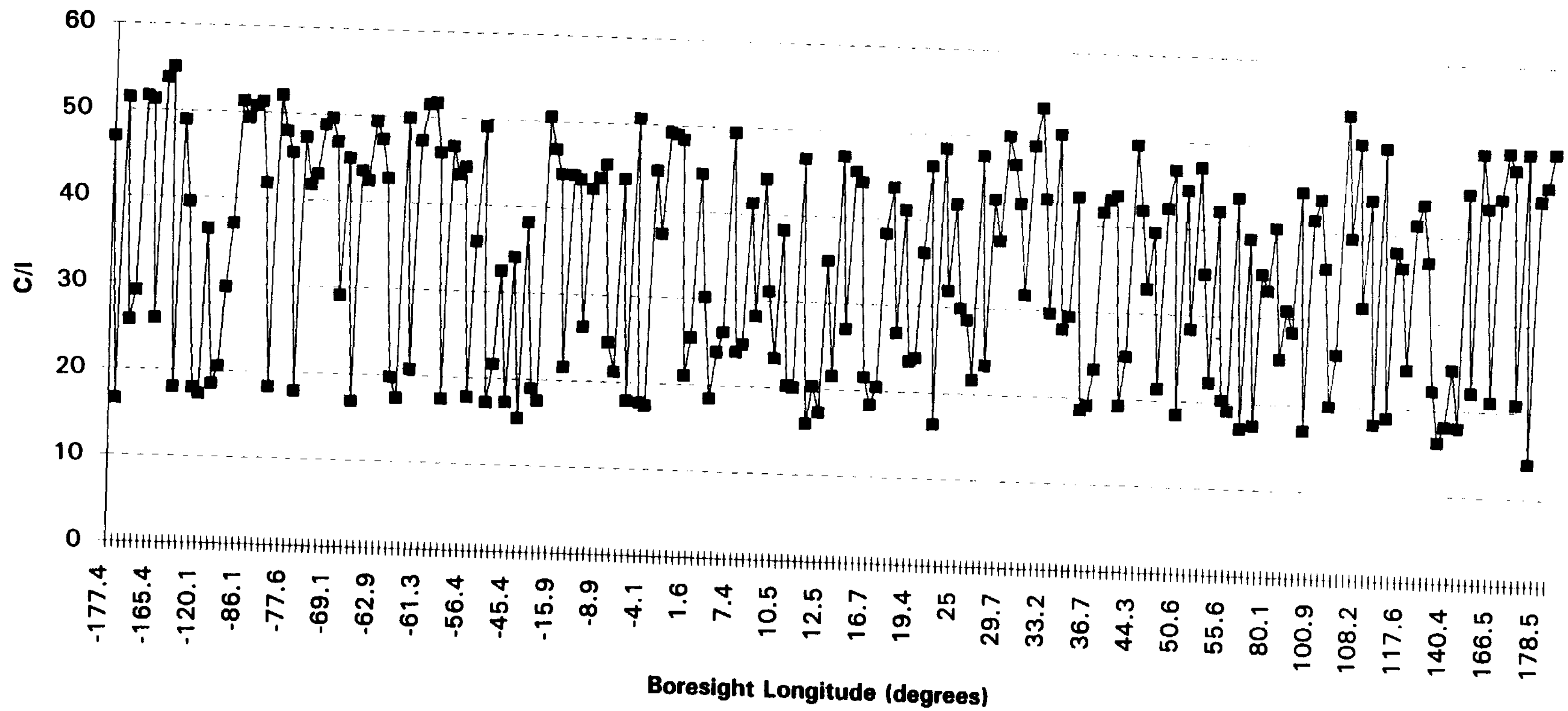
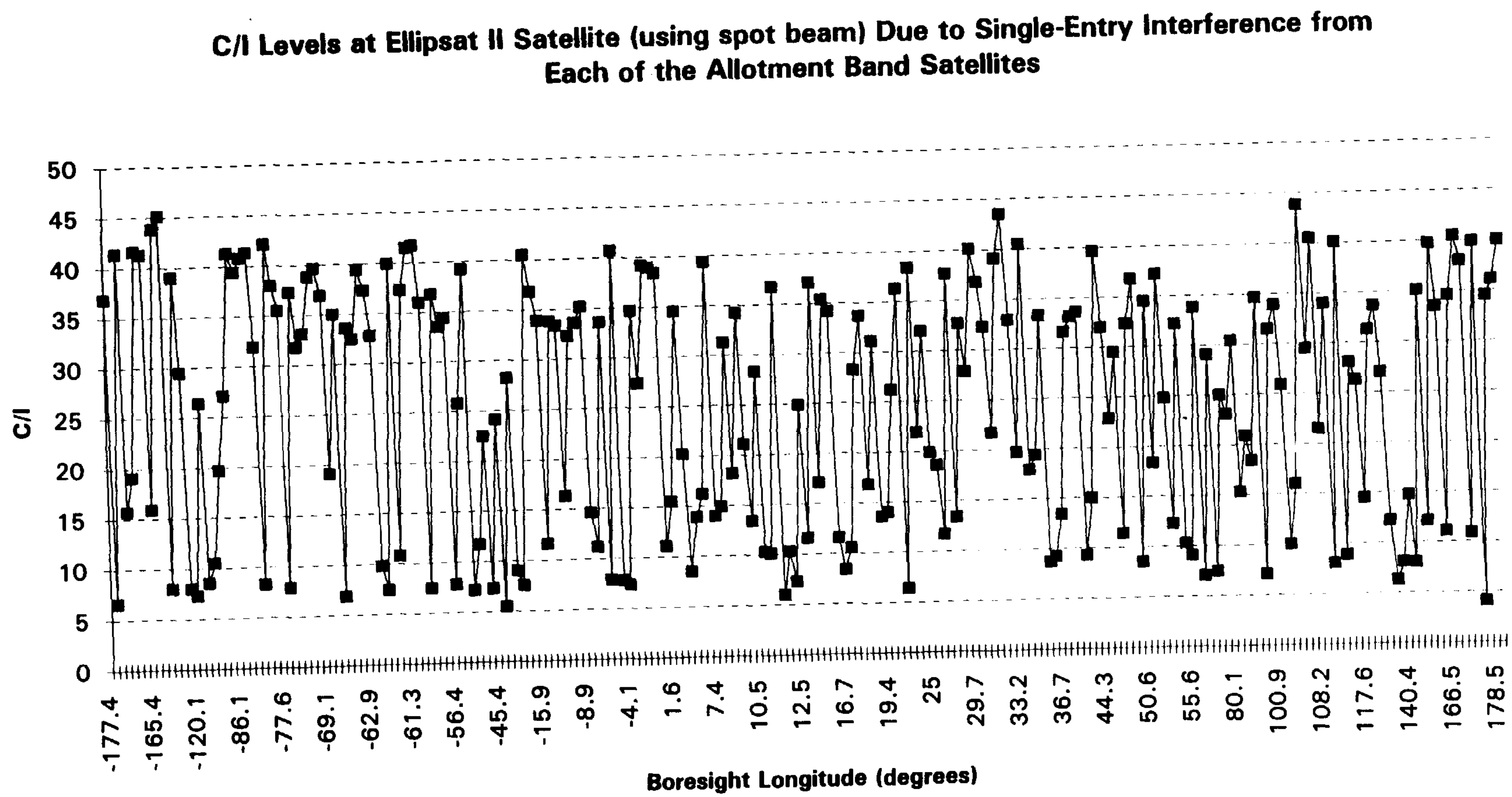


Figure 5.



C/I Levels at Ellipsat II Satellite (using spot beam) Due to Single-Entry Interference from Each of the Allotment Band Satellites
C/I
50
45
40
35
30
25
20
15
10
5
0
-177.4
-165.4
-120.1
-86.1
-77.6
-69.1
-62.9
-61.3
-56.4
-45.4
-15.9
-8.9
-4.1
1.6
7.4
10.5
12.5
16.7
19.4
25
29.7
33.2
36.7
44.3
50.6
55.6
80.1
100.9
108.2
117.6
140.4
166.5
178.5
Boresight Longitude (degrees)

Figure 6.

C/I Levels at Each Allotment Band Satellite Due to Single-Entry Interference from Globalstar Satellite

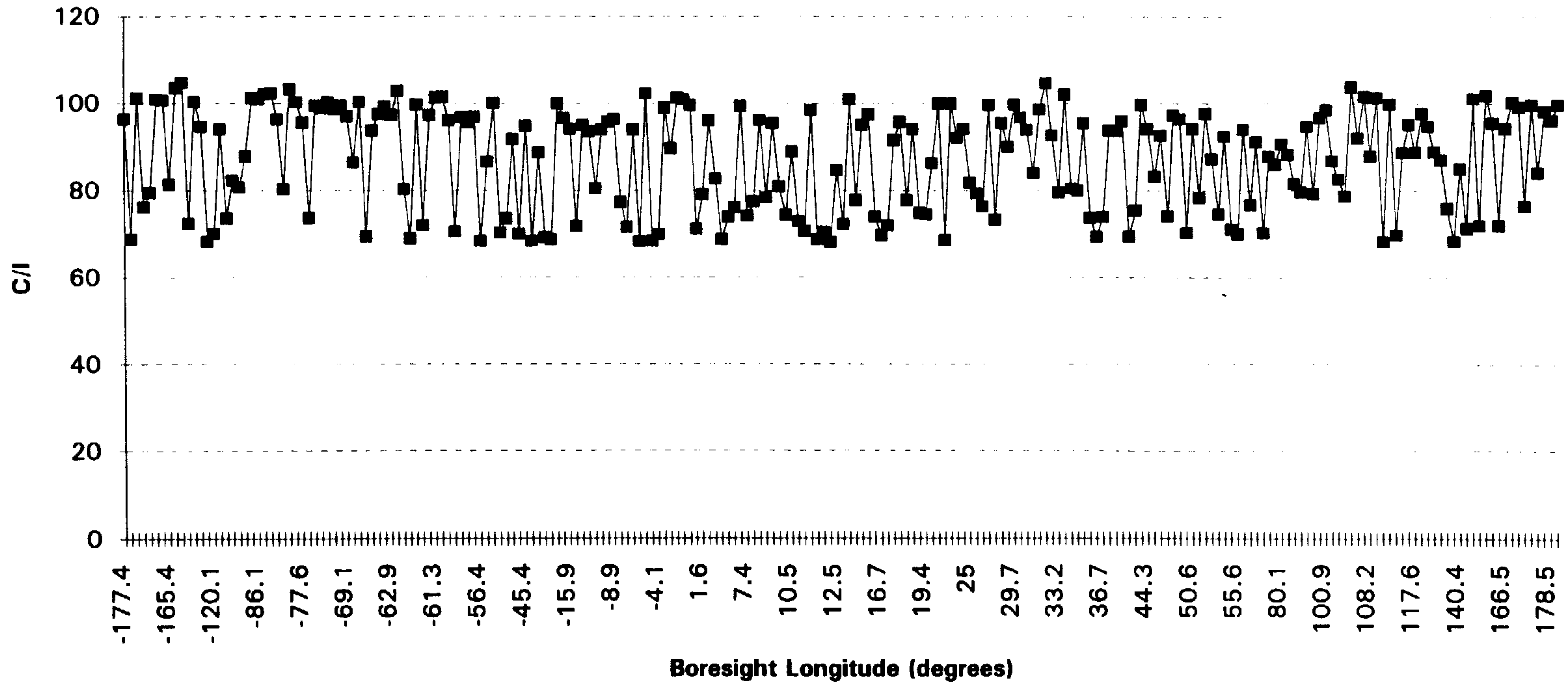


Figure 7.

C/I Levels at Each Allotment Band Satellite Due to Single-Entry Interference from Aries Satellite

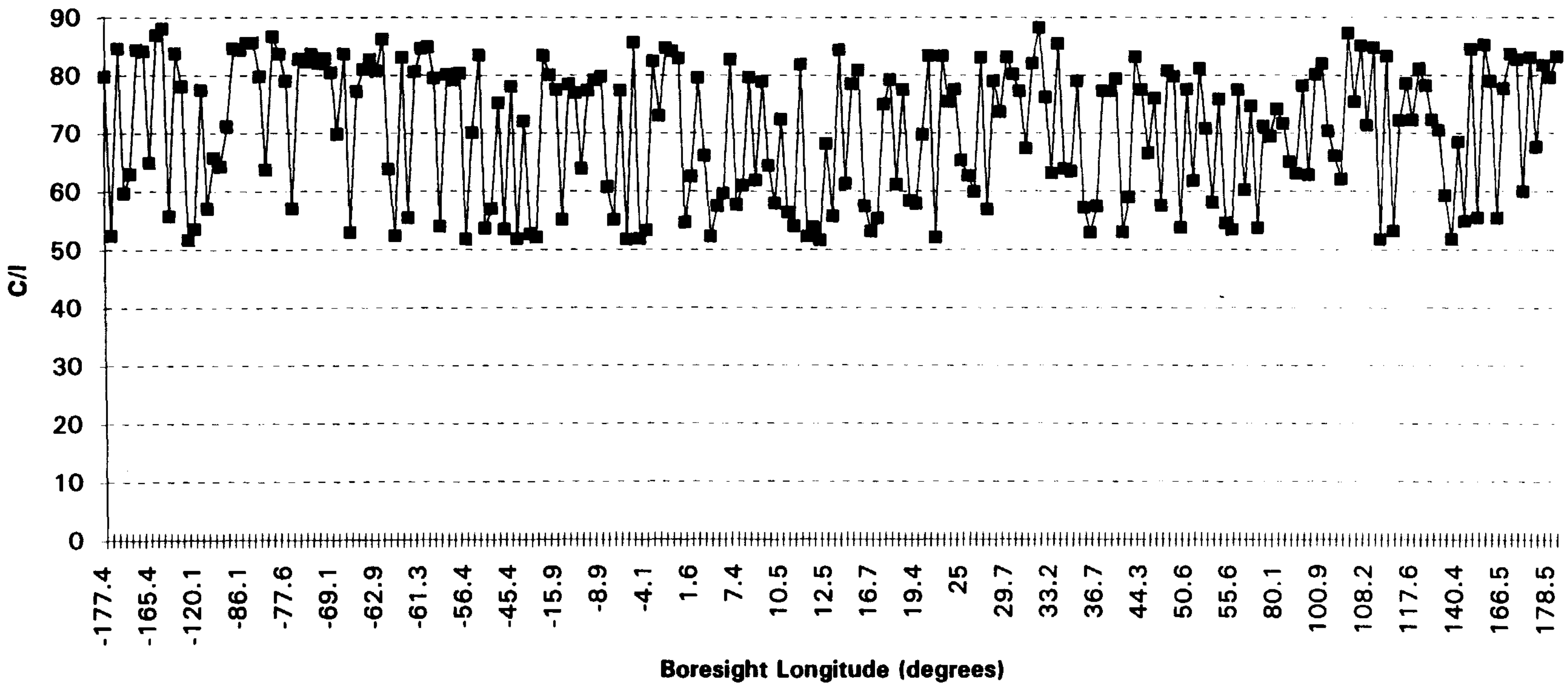


Figure 8.

C/I Levels at Each Allotment Band Satellite Due to Single-Entry Interference from Ellipsat I Satellite

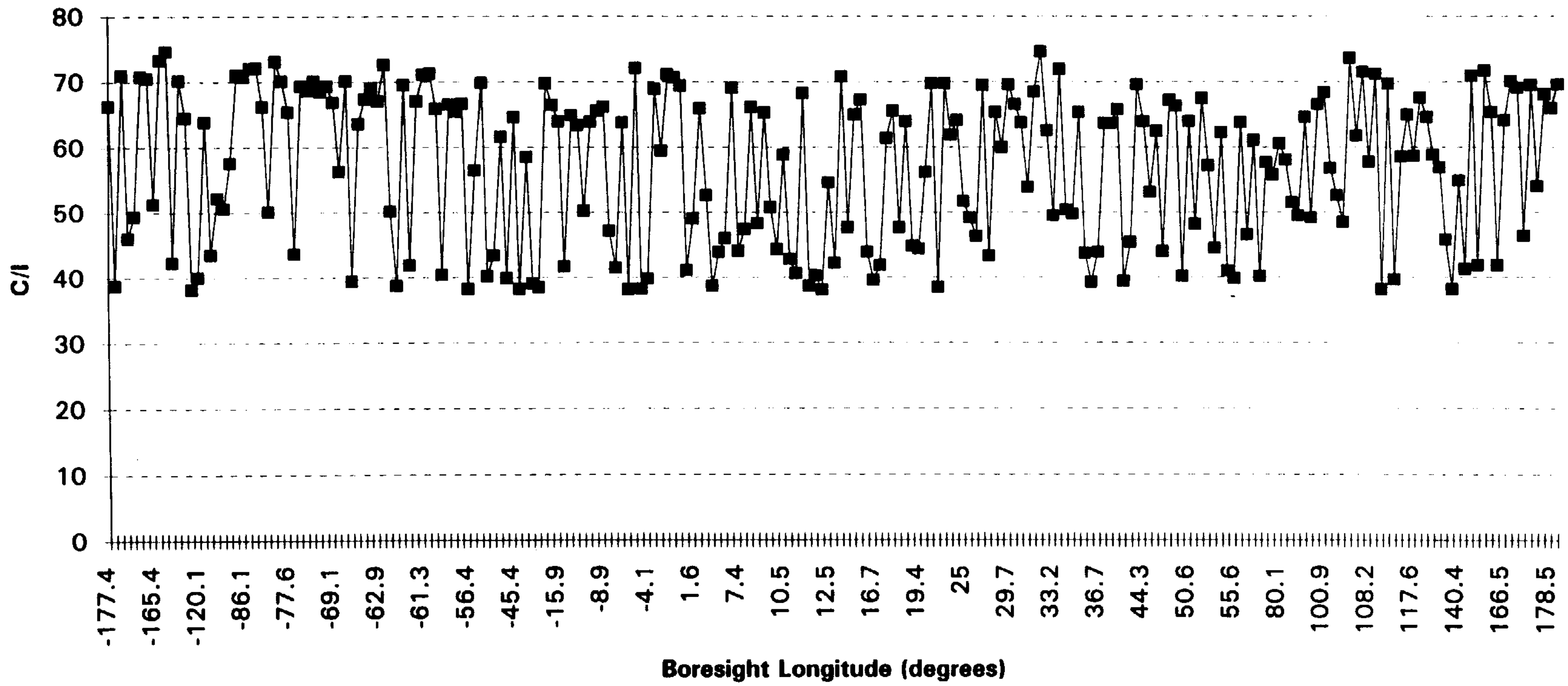


Figure 9.

C/I Levels at Each Allotment Band Satellite Due to Single-Entry Interference from Ellipsat II Satellite

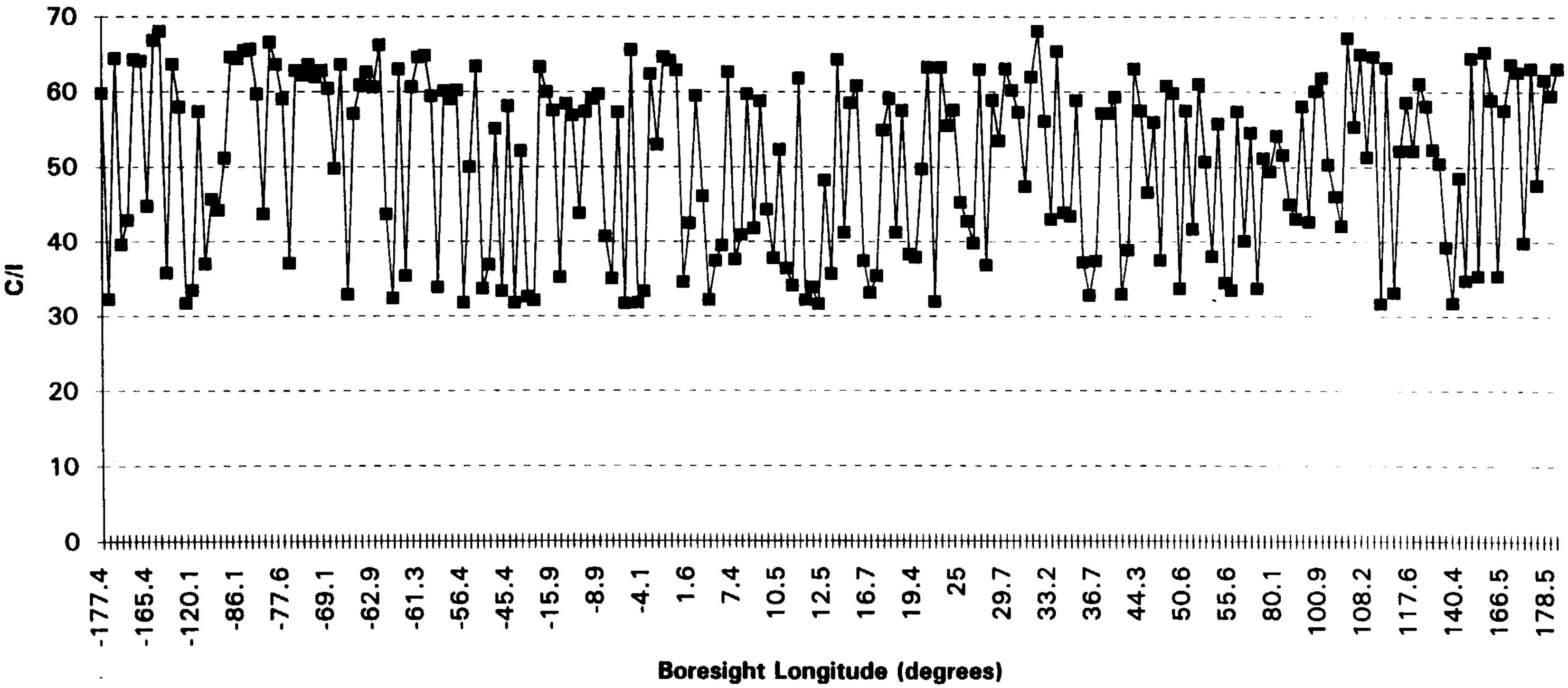


Figure 10.

Annex

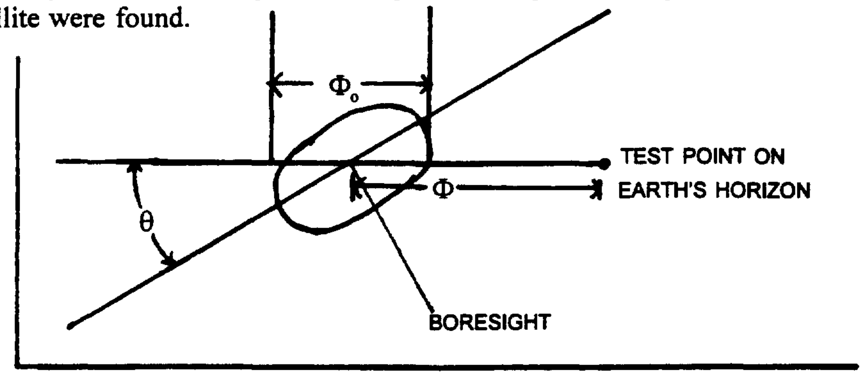
1. Model Description

Using RBW, trans-horizon interference will occur only between antipodal satellites. To calculate the C/I ratio at the NGSO satellite, it is necessary to determine the geometry between the GSO satellite and the Earth's horizon for each of the allotment plan beams.

1.1.1 Interfering GSO ABS parameters

From the GSO satellite, it is easiest to picture the Earth projected onto a two-dimensional plane taken as the plane tangent to the Earth. By doing this, the earth can be viewed in a two-dimensional "true" view which is directly correlated to the satellite reference system since a linear dimension in the perspective plane subtends a specific angle from the satellite. The utility of the perspective plane derives from the fact that the elliptical beam, projected onto the Earth's surface for each of the beams in the allotment plan, represents a constant e.i.r.p. from the satellite. When the ellipse is pictured in the perspective plane, it is possible to calculate the off-axis angle of a test point from the satellite boresight.

Using the allotment plan parameters in Appendix 30B (boresight, orbital position, major axis, minor axis) and the geometry of the "perspective plane", test points along the Earth's horizon as seen from the GSO satellite were found.



Next, Φ and Φ_o were determined where Φ is the off-axis angle of a test point from the boresight and Φ_o is the cross-sectional half-power beamwidth in the direction of the test point. The following equation was used to calculate Φ_o:

$$\Phi_o = \sqrt{\frac{1}{\left(\frac{\cos\theta}{a}\right)^2 + \left(\frac{\cos\theta}{b}\right)^2}}$$

where: θ is the angle between the major axis of the ellipse and the vector from the boresight to the test point (degrees),

a is the major axis of the ellipse (degrees),

b is the minor axis of the ellipse (degrees).

Φ and Φ_o were used to calculate the gain of the satellite antenna at each test point from the formula in Section 1.7.2 of Appendix 30B. The isolation from the main beam gain was determined for each of the horizon test points. Using the minimum value of isolation and the satellite e.i.r.p. density, the power density at the GSO satellite in the direction of the Earth's horizon was found. The interfering power, I